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Module 5

Stormwater Quantity Requirements

Virginia Department of Environmental Quality

5a. Stormwater Quantity Requirements - Overview

The Evolution of MS-19

The regulatory Drivers:

- The Erosion & Sediment Control (ESC) Regulations
- Stormwater Management (SWM) Regulations (Part IIC)
- SWM Law
- SWM Regulations (Part IIB)

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ESC Regulations: Minimum Standard 19

9VAC25-840-40.19.

Concentrated stormwater runoff leaving a development site shall be discharged directly into an adequate natural or man-made receiving channel, pipe or storm sewer system.

Adequacy of all channels and pipes shall be verified in the following manner . . . .

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SWM Regulations (Part IIC): Minimum Standard 19 (redux)

9VAC25-870-97. Stream channel erosion.

The VSMP authority shall require compliance with subdivision 19 of 9VAC25-840-40 of the ESC Regulations.

VSMP authority may determine that some watersheds require enhanced criteria :

1-year Extended Detention (ED)

Channel Protection ‘safe harbor’

§ 62.1-44.15:28.10 require that VSMPs . . . .

- Where TMDL or exceptional waters require more stringent control the following shall satisfy any regulatory requirements for natural channel capacity:
  - (i) 48 hour ED of the WQv (0.5”);
  - (ii) 24-hour ED of the 1-yr storm runoff; and
  - (iii) proportional reduction of the 1.5, 2, and 10-yr storms peak flow rate using forested condition energy balance.

SWM Regulations (Part IIB): Quantity Control

Meet the new boss . . .

. . . Same as the old boss?

9VAC25-870-66. Water quantity.

Channel Protection.

Channel protection and flood protection minimum standards are established pursuant to the requirements of subdivision 7 of § 62.1-44.15:28 of the Code of Virginia.

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SWM Regulations (Part IIB): Quantity Control

9VAC25-870-66. Water quantity.

Channel Protection.

Compliance with the minimum standards set out in this section shall be deemed to satisfy the requirements of subdivision 19 of 9VAC25-840-40 (Minimum standards; Virginia Erosion and Sediment Control Regulations).

Primary Regulatory Driver: SWM Law

§ 62.1-44.15:28 A.10

Require that VSMPs:

- **Replicate**, as nearly as practicable, existing predevelopment runoff characteristics and site hydrology, or
- **Improve upon** contributing share of predevelopment stream channel erosion or localized flooding

Circle Back to ESC Law & Regulations

§ 62.1-44.15:52. ESC Law.

- After July 1, 2014, flow rate capacity requirements
  - **SWM Water Quantity Requirements**

    (§ 62.1-44.15:24 et seq.) and attendant regulations (9VAC25-870-66)
  - Unless grandfathering provisions apply

5b. Channel Protection Criteria

& the Energy Balance Method

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9VAC25-870-66. Water quantity.

Channel Protection:

Concentrated stormwater flow shall be released in to a stormwater conveyance system:

Photo: Williamsburg Environmental Group

Photo: City of Charlottesville

System Capacity

"***Manmade stormwater conveyance system***" *means a pipe, ditch, vegetated swale, or other stormwater conveyance system constructed by man except for restored stormwater conveyance systems*

System Capacity

Manmade stormwater conveyance system:

- Non-erosive capacity for **2-yr peak flow** & **1% Rule** analysis **OR**
- Energy Balance (Natural Stormwater Conveyance)

System Capacity

"***Restored stormwater conveyance system***" *means a stormwater conveyance system that has been designed and constructed using natural channel design concepts. Includes the main channel and the flood-prone area adjacent to the main channel.*

Photo: Williamsburg Environmental Group

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Restored stormwater conveyance system:

- Development (density, scale, etc.) and peak flow rate consistent with the design parameters of the restored system & **1% Rule** analysis **OR**
- Energy Balance (Natural Stormwater Conveyance)

Photo: City of Charlottesville

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System Capacity

"***Natural stormwater conveyance system***" *means the* *main channel* *of a natural stream and the* *flood-prone area* *adjacent to the main channel.*

Photo: Ellanor C. Lawrence Park Fairfax, County

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Criteria for the Protection of Natural Channels

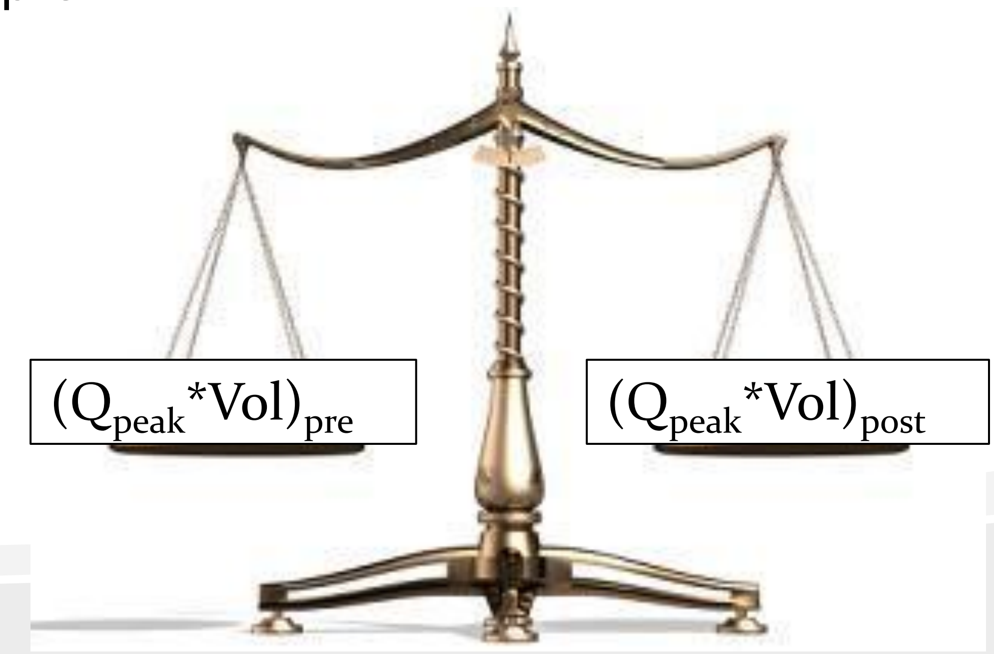
Protection of natural stream channels

- Restore them using natural channel design
- Protect them using the Energy Balance Method (1-yr event)
- Safe Harbor Provision (from SWM Law § 62.1-44.15:28.10)

Energy Balance

Goal: Establish "balance" exerted by pre- and post-developed stormwater discharge

($Qpeak_{pre}$*Vol) with 10% improvement factor



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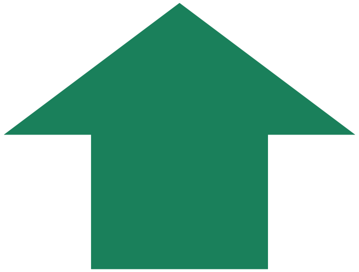
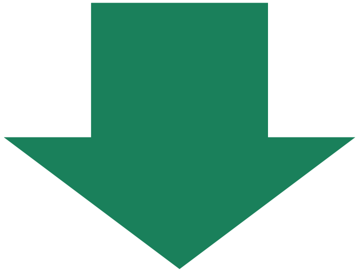
What is Energy Balance & Why use it?



Post-development runoff volume increases



Allowable discharge decreases

Simple **"balance"** offsets increase in volume and peak flow of developed condition hydrology

Stormwater Quantity Channel Protection

9VAC25-870-66.A

Energy Balance

Post ($Vol_{1\text{-}yr}$ * Peak $Q_{1\text{-}yr}$) ≤ **Pre** ($Vol_{1\text{-}yr}$ * Peak $Q_{1\text{-}yr}$)

$$Q_{1post} \leq Q_{1pre}\left(\frac{Pre\ Vol_1}{Post\ Vol_1}\right)(IF)$$

IF = Improvement Factor:

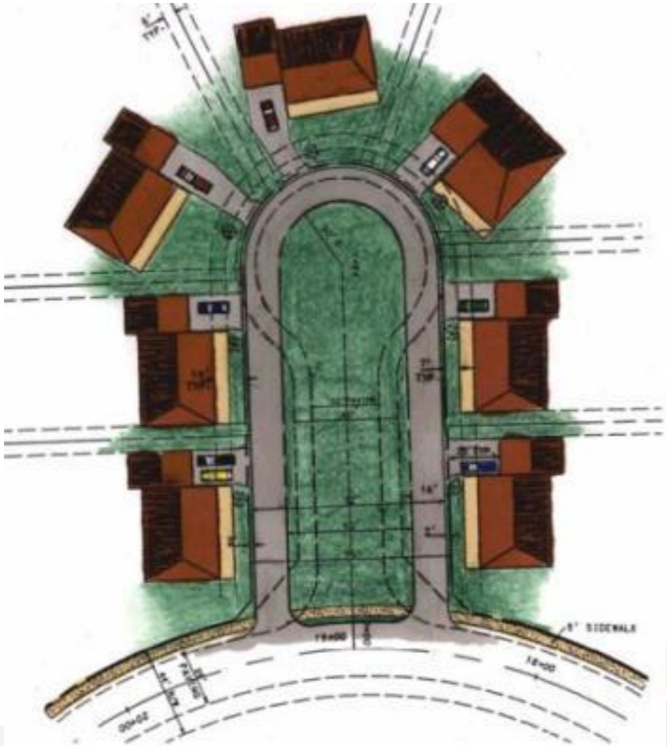
(0.8 for sites > 1 acre or 0.9 for sites ≤ 1 acre)

Why Energy Balance?

§ 62.1-44.15:28 A.11.

Encourage:

- Low-impact development designs
- Nonstructural means for controlling stormwater
- Regional/watershed approaches



How Does Energy Balance encourage LID?

- Decrease volume by **self-crediting site design**
  - Less impervious cover
  - Minimizing impacts to native vegetation
  - Minimize impacts to native soils
- Decrease volume by utilizing **structural** and **non-structural Runoff Reduction practices**

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How Does Energy Balance encourage LID

- Use VRRM Spreadsheet to calculate the volume reduction with a **double credit**:
  - **Reduced** Vol_{post1} for Energy Balance Equation; and
  - **Reduced** Curve Number (CN) for computing the Q_{1post}

How Does Energy Balance encourage LID

$$Q_{1post} \leq Q_{1pre}\left(\frac{Vol_{pre1}}{Vol_{post1}}\right)(IF)$$

Better site design reduces post-development runoff volume

- As Vol_{post1} reduced
- Vol_{pre1}/Vol_{post1} ratio increases
- Results in increase in allowable Q_{1post}

***Decreases storage required for peak flow**

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Improvement Factor (*IF*)

§ 62.1-44.15:28

- requires stormwater regulations to *improve upon contributing share of existing predevelopment runoff characteristics and site hydrology . . . .*
- At minimum, pre-developed discharge will be reduced using factor of 0.8 or 0.9

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Energy Balance Terminology

$$Q_{1post} \leq Q_{1pre}\left(\frac{Pre\,Vol_1}{Post\,Vol_1}\right)(IF)$$

Description	Units	Term
	NRCS TR-55	
Runoff Depth	inches (in)	*Q*
Runoff Volume	cubic feet (ft^3) or acre feet (ac.ft.)	*Vr*
Storage Volume	cubic feet (ft^3) or acre feet (ac.ft.)	*Vs*
Peak Discharge	cubic feet per second (cfs)	q_p
	VRRM Treatment Volume Runoff Coefficients	
Unit-less Volumetric Runoff Coefficients		*Rv*
	VRRM Curve Number Adjustment	
Runoff Depth	inches	*RV*
	VSMP Regulations Channel Protection Criteria (4VAC50-60-66.B)	
Peak Discharge	cubic feet per second (cfs)	*Q*
Runoff Volume*	cubic feet (ft^3) or acre feet (ac.ft.)*	*RV*

*Units of volume in the VSMP regulations Channel Protection Criteria can also be expressed in terms of *watershed-inches* or inches (consistent with Runoff Depth as expressed in the VRRM *CN* adjustment.

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Energy Balance: 9VAC25-870-66.A

- How would you write this equation:

$$Q_{1post} \leq Q_{1pre}\left(\frac{Pre\ Vol_1}{Post\ Vol_1}\right)(IF)$$

$$q_{1post} \leq q_{1pre}\left(\frac{RV_{pre1}}{RV_{post1}}\right)(IF)$$

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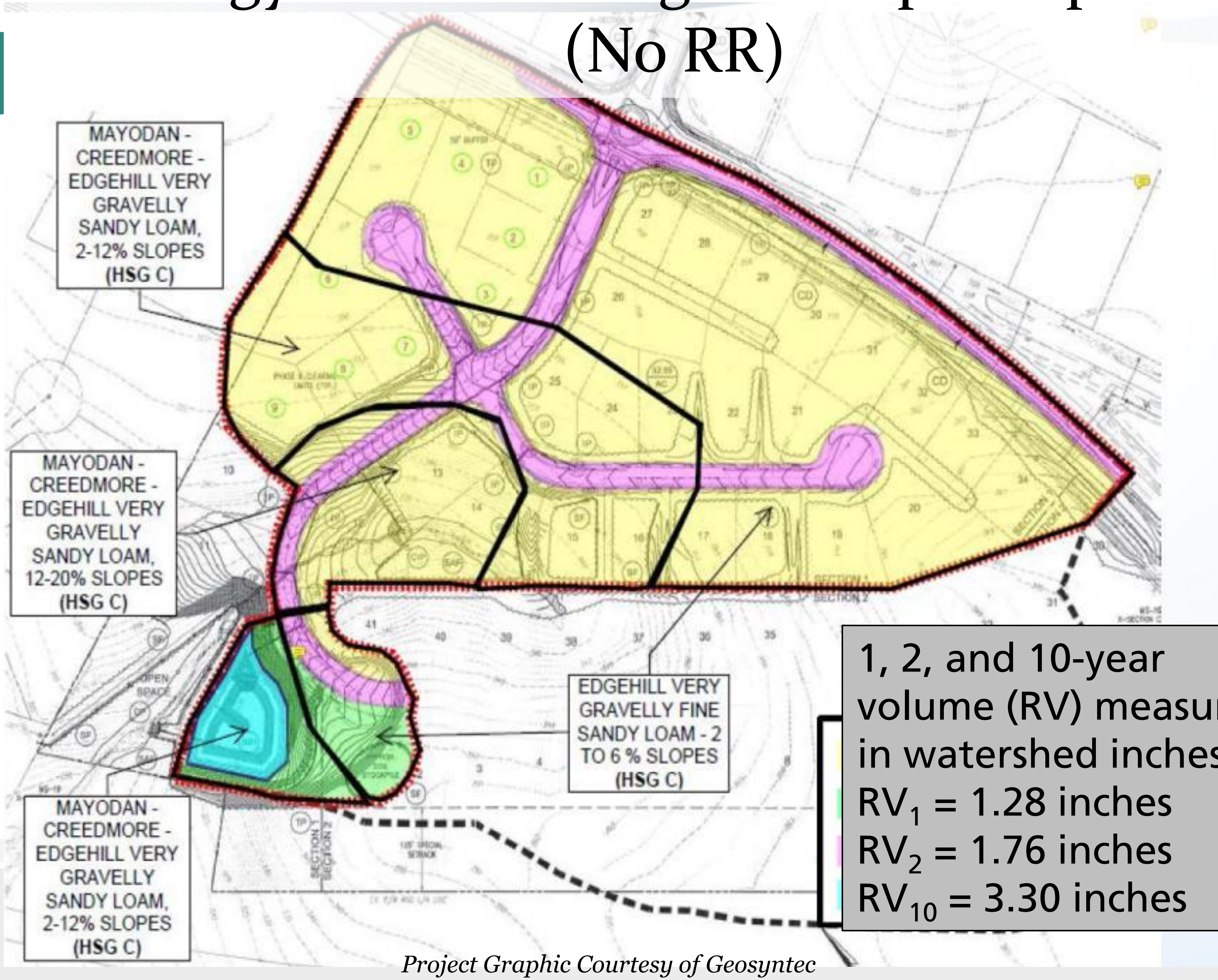
5c. Energy Balance Design Example

PG 13

Energy Balance Design Example: Option 1 (No RR)



1, 2, and 10-year volume (RV) measured in watershed inches

RV_1 = 1.28 inches

RV_2 = 1.76 inches

RV_{10} = 3.30 inches

Project Graphic Courtesy of Geosyntec

Where Does the Runoff Depth come From?

Figure 2-1

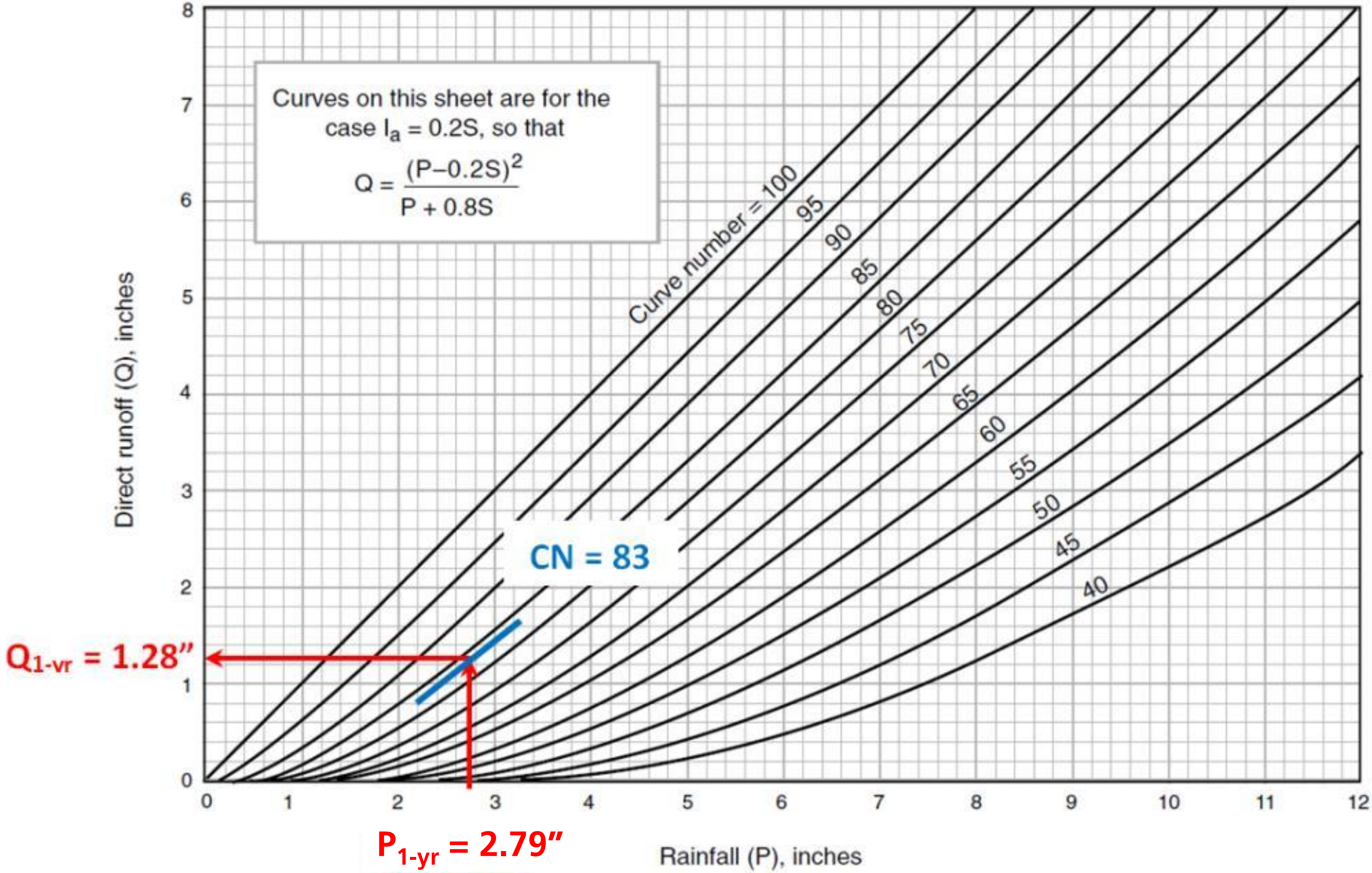


Table 2-1

Where Does the Runoff Depth come From?

CN = 83

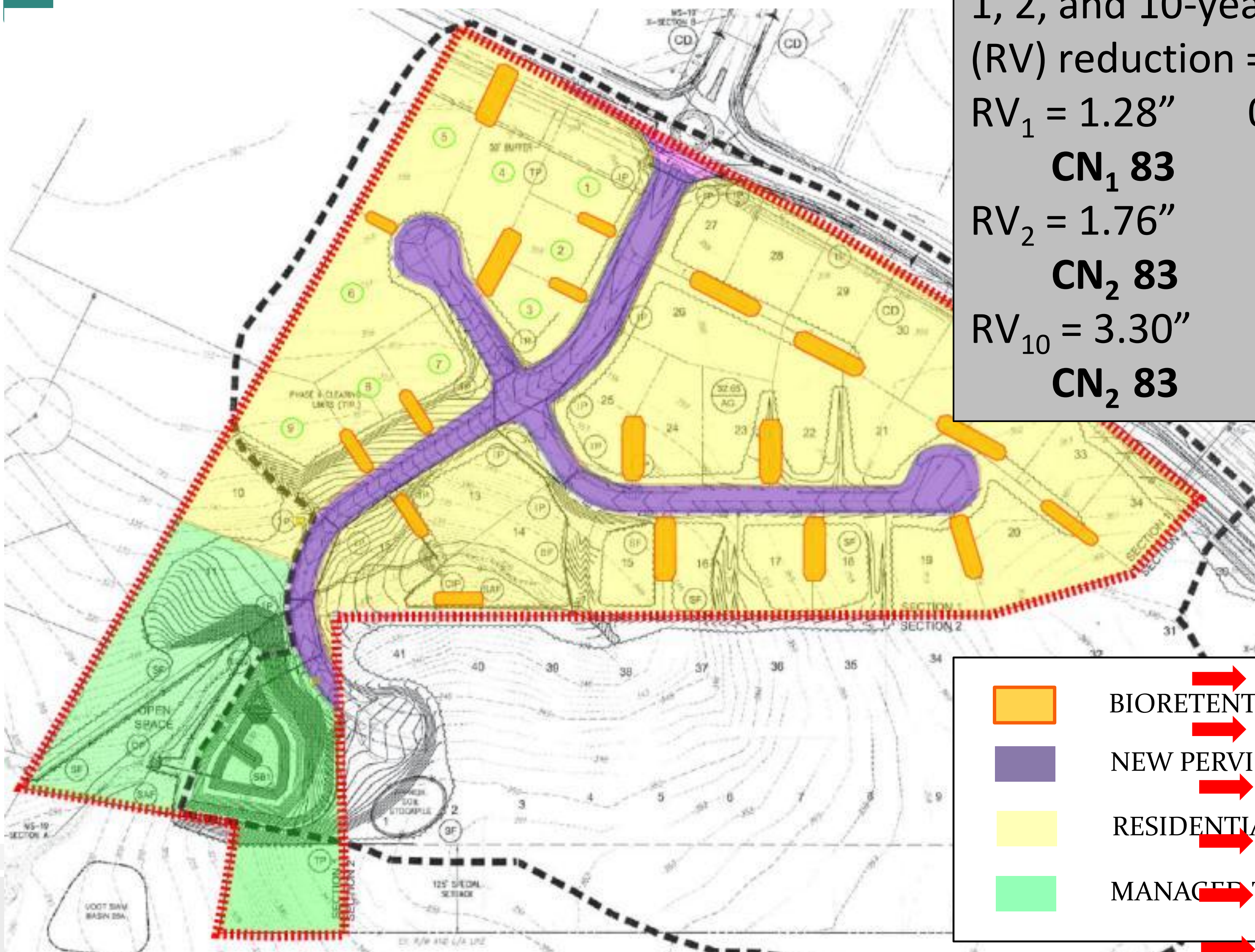
$P_{1\text{-}yr}$ = 2.79”

1.28”

Rainfall	Runoff depth for curve number of— 40	45	50	55	60	65	70	75	80	85	90	95	98
	inches												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	[illegible]	[illegible]	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	[illegible]	[illegible]	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

1/ Interpolate the values shown to obtain runoff depths for CN's or rainfall amounts not shown.

Energy Balance Design Example: Option 2 with RR



1, 2, and 10-year volume (RV) reduction =

RV_1 = 1.28” 0.96”

CN_1 83 77

RV_2 = 1.76” 1.44”

CN_2 83 78

RV_{10} = 3.30” 2.98”

CN_2 83 80

	BIORETENTION CELLS
	NEW PERVIOUS PAVEMENT
	RESIDENTIAL LOTS
	MANAGED TURF

Project Graphic Courtesy of Geosyntec

Channel & Flood Protection Tab

		1-year storm	2-year storm	10-year storm
Target Rainfall Event (in)		2.79	3.38	5.14
Drainage Area A				
Drainage Area (acres)	19.80			
Runoff Reduction Volume (cf)	23,065			
Drainage Area B				
Drainage Area (acres)	0.00			
Runoff Reduction Volume (cf)	0			
Drainage Area C				
Drainage Area (acres)	0.00			
Runoff Reduction Volume (cf)	0			
Drainage Area D				
Drainage Area (acres)	0.00			
Runoff Reduction Volume (cf)	0			
Drainage Area E				
Drainage Area (acres)	0.00			
Runoff Reduction Volume (cf)	0			

Based on the use of Runoff Reduction practices in the selected drainage areas, the spreadsheet calculates an adjusted $RV_{Developed}$ and adjusted Curve Number.

Drainage Area A		A soils	B Soils	C Soils	D Soils
Forest/Open Space -- undisturbed, protected forest/open space or reforested land	Area (acres)	0.00	0.00	0.40	0.00
	CN	30	55	70	77
Managed Turf -- disturbed, graded for yards or other turf to be mowed/managed	Area (acres)	0.00	0.00	12.13	0.00
	CN	39	61	74	80
Impervious Cover	Area (acres)	0.00	0.00	7.27	0.00
	CN	98	98	98	98

Weighted CN	S
83	2.05

	1-year storm	2-year storm	10-year storm
$RV_{Developed}$ (in) with no Runoff Reduction	1.28	1.76	3.30
$RV_{Developed}$ (in) with Runoff Reduction	0.96	1.44	2.98
Adjusted CN	77	78	80

1, 2, and 10-year storm rainfall depths

Volume Reduction = 23,065 ft^3

1, 2, and 10-year volume (RV) reduction =

$RV_1 = 1.12'' \rightarrow 0.96''$

$\mathbf{CN_1 = 83 \rightarrow 77}$

$RV_2 = 1.54'' \rightarrow 1.44''$

$\mathbf{CN_2 = 83 \rightarrow 78}$

$RV_{10} = 2.98'' \rightarrow 2.98''$

$\mathbf{CN_2 = 83 \rightarrow 80}$

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Curve Number Adjustment

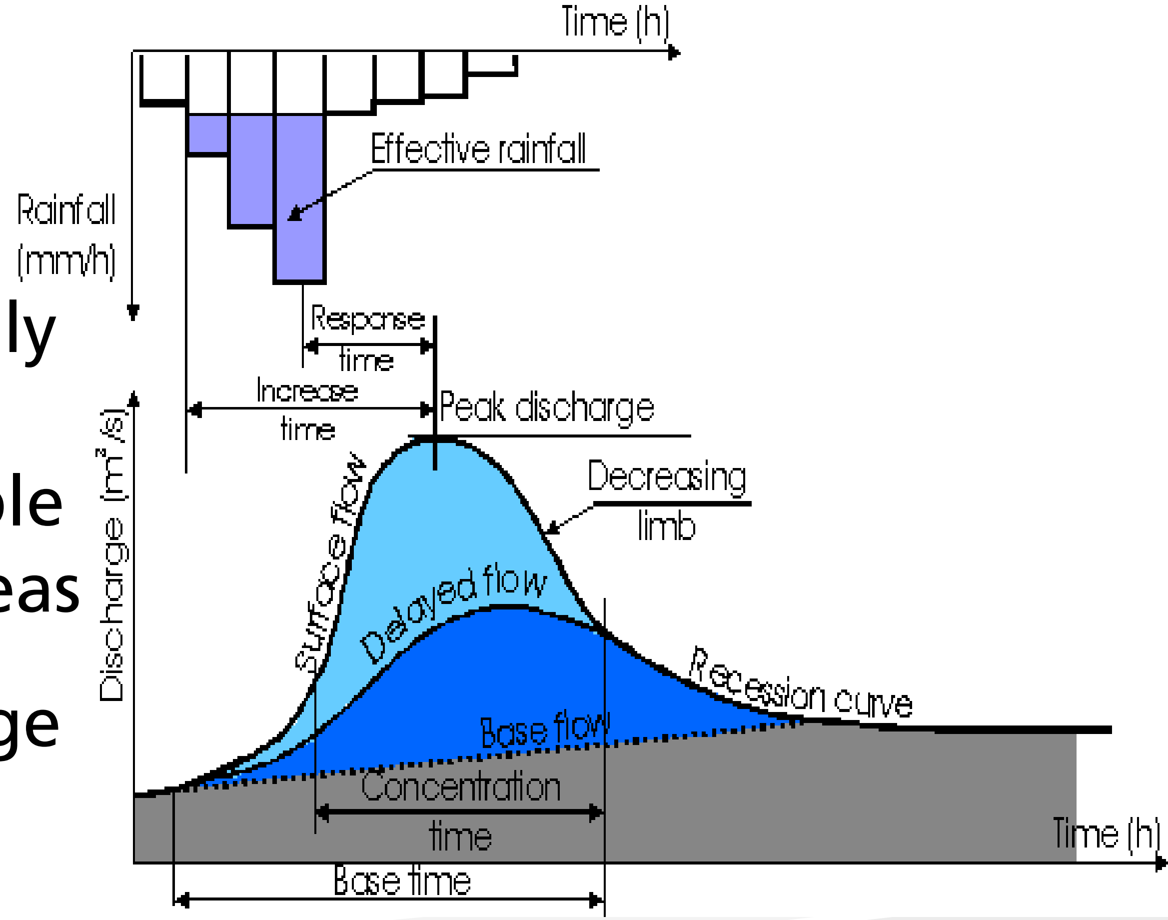
Challenge:

- Provide quantity “credit” for distributed retention practices
- Avoid Complex routing/modeling of multiple practices, yet simulate single event modeling
- Allow designers to target volume as primary metric (quantity and quality)
- Various methods explored by VA TAC

Hydrograph Modification

Simplifying Assumptions:

- Retention uniformly distributed if considering multiple features or sub-areas
- Negligible discharge from under-drains (if any)

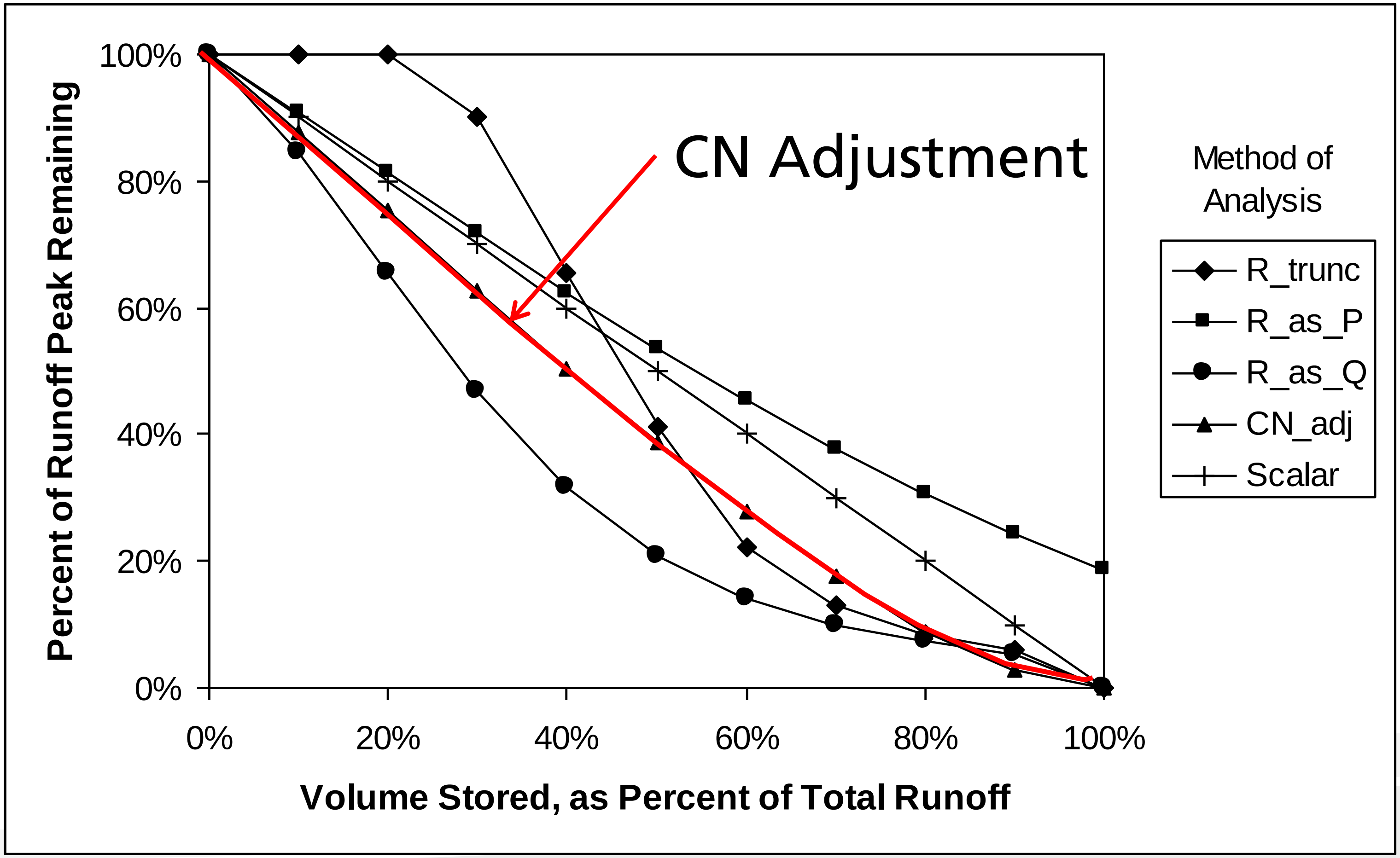


Hydrograph Modification

Methods Considered:

1. Hydrograph Truncation
2. Hydrograph Scalar Multiplication
3. Precipitation Adjustment
4. Runoff Adjustment
5. Curve Number Adjustment

5 Methods Considered; Curve Number Adjustment Selected



Excerpted from work by Paul R. Koch, Ph.D., P.E.

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Does It Really Work?

Reported Reductions in Runoff Volume:

Losses Due to Exfiltration, Evapotranspiration and Post Storm Delivery

- Sampling of reductions reported by research:

CT: 99%	PA: 80%
UK: 58%	Aus: 73%
FL: 98%	WA: 96%
NC: 30 to 65%	MD: 46 to 54%

Does It Really Work?

Photo: Conservation Design Forum

- Extended Filtration of Bioretention systems mimic pre-developed hydrologic response (an undeveloped watershed)
- Permeable Pavement systems equipped with underdrains demonstrate significant RR
  - Extended discharge that can be considered negligible in comparison to surface runoff from other areas of site

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Curve Number Adjustment: Hydrograph Modification

Runoff Depth Equations (TR-55):

Eq. 2-1: $$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Eq. 2-2: $$I_a = 0.2S$$

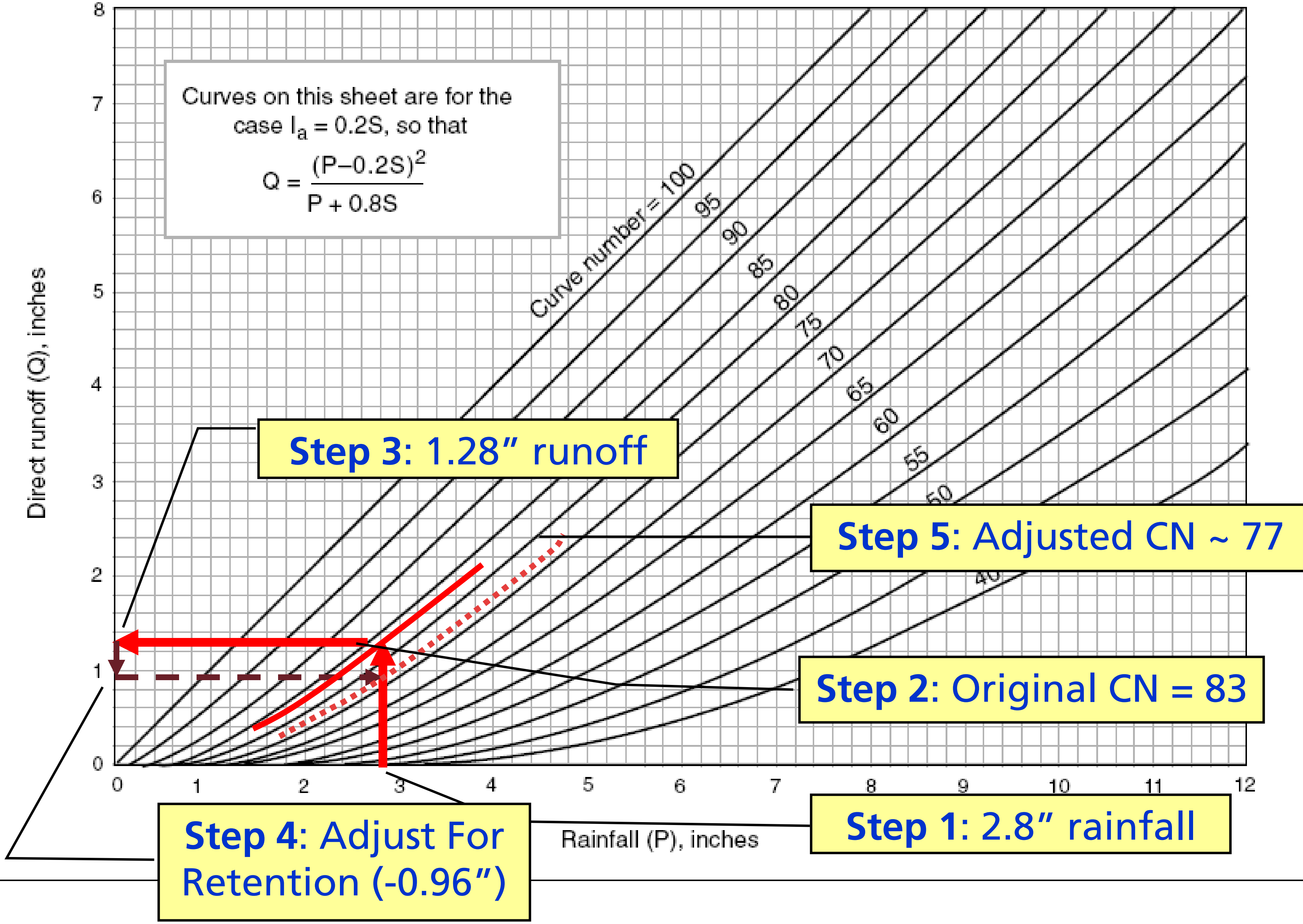
Eq. 2-4: $$S = \frac{1000}{CN} - 10$$

Where:

- Q = runoff depth (in)
- P = precipitation depth (in)
- S = potential maximum retention after runoff begins
- I_a = initial abstraction, volume that must be filled before runoff begins

Figure 2-1 Solution of runoff equation.

PG 14-15



Channel & Flood Protection Tab

	A	B	C	D	E	F	G	H
1				1-year storm	2-year storm	10-year storm		
2	Target Rainfall Event (in)			2.79	3.38	5.14		
3								
4	Drainage Area A							
5	Drainage Area (acres)		19.80					
6	Runoff Reduction Volume (cf)		23,065					
7								
8	Drainage Area B							
9	Drainage Area (acres)		0.00					
10	Runoff Reduction Volume (cf)		0					
11								
12	Drainage Area C							
13	Drainage Area (acres)		0.00					
14	Runoff Reduction Volume (cf)		0					
15								
16	Drainage Area D							
17	Drainage Area (acres)		0.00					
18	Runoff Reduction Volume (cf)		0					
19								
20	Drainage Area E							
21	Drainage Area (acres)		0.00					
22	Runoff Reduction Volume (cf)		0					
23								
24								
25	Based on the use of Runoff Reduction practices in the selected drainage areas, the spreadsheet calculates an adjusted $RV_{Developed}$ and adjusted Curve Number.							
26								
27	Drainage Area A			A soils	B Soils	C Soils	D Soils	
28	Forest/Open Space -- undisturbed, protected forest/open		Area (acres)	0.00	0.00	0.40	0.00	
29	space or reforested land		CN	30	55	70	77	
30	Managed Turf -- disturbed, graded for yards or other turf to be		Area (acres)	0.00	0.00	12.13	0.00	
31	mowed/managed		CN	39	61	74	80	
32			Area (acres)	0.00	0.00	7.27	0.00	
33	Impervious Cover		CN	98	98	98	98	
34							Weighted CN	S
35							83	2.05
36				1-year storm	2-year storm	10-year storm		
37	$RV_{Developed}$ (in) with no Runoff Reduction			1.28	1.76	3.30		
38	$RV_{Developed}$ (in) with Runoff Reduction			0.96	1.44	2.98		
39			Adjusted CN	77	78	80		

1, 2, and 10-year storm rainfall depths

Volume Reduction = 23,065 ft^3

1, 2, and 10-year volume (RV) reduction =

RV_1 = 1.12” → 0.96”

CN_1 = 83 → 77

RV_2 = 1.54” → 1.44”

CN_2 = 83 → 78

RV_{10} = 2.98” → 2.98”

CN_2 = 83 → 80

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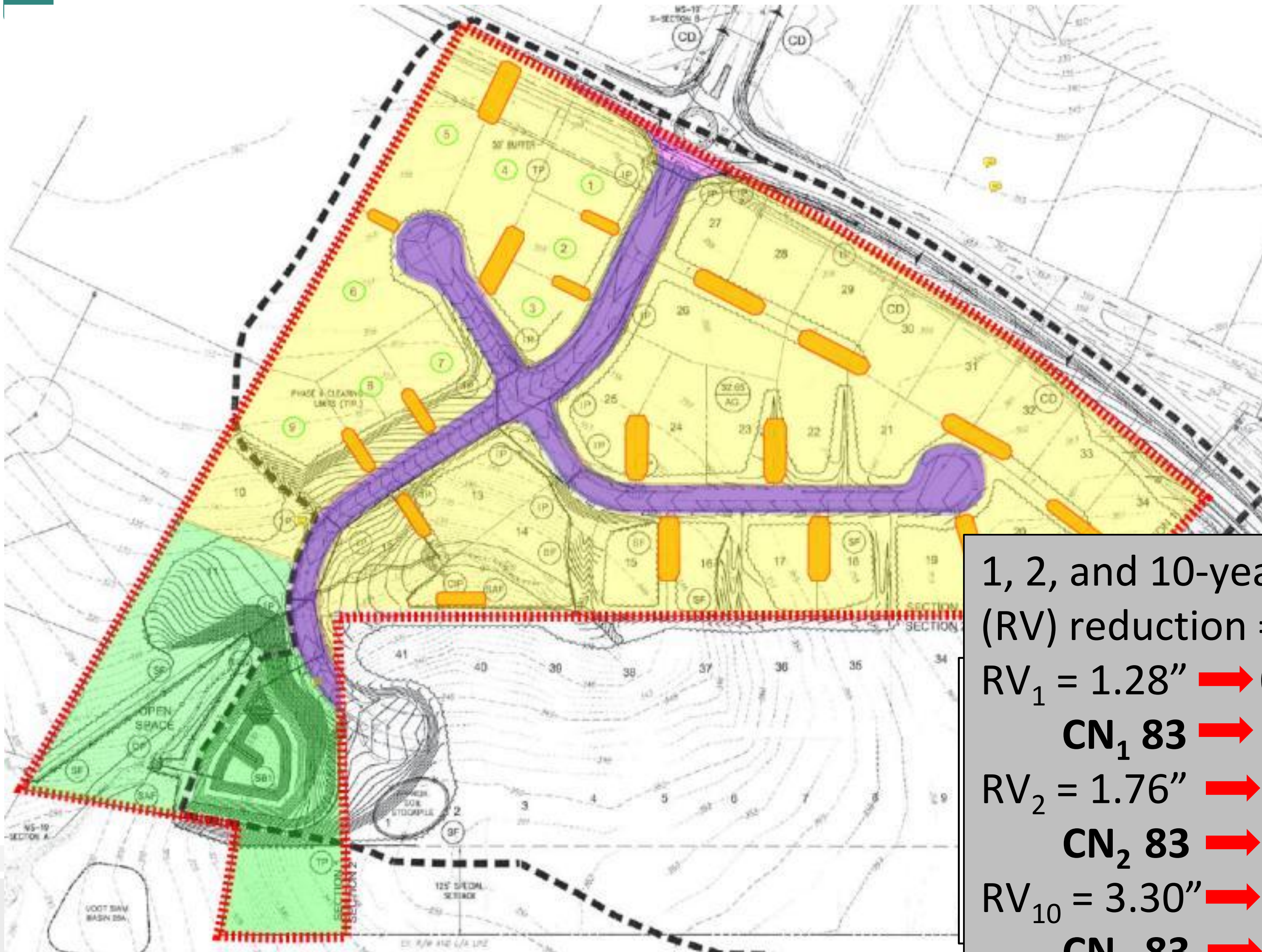
Energy Balance Design Example: Option 2 with RR



1, 2, and 10-year volume (RV) reduction =

RV_1 = 1.28” ➡ 0.96”

CN_1 83 ➡ 77

RV_2 = 1.76” ➡ 1.44”

CN_2 83 ➡ 78

RV_{10} = 3.30” ➡ 2.98”

CN_2 83 ➡ 80

Project Graphic Courtesy of Geosyntec

Energy Balance Design Example

One-Year Storm Hydrology Summary: 19.8 acres			
	Pre-Developed	**Post-Developed no RR**	**Post-Developed with RR**
Runoff Curve Number	71	83	77
Runoff Volume (RV)	0.62 in	1.28 in	0.96 in
Runoff Volume	1.02 ac-ft.	2.11 ac-ft.	1.58 ac-ft.
Peak Discharge (q_1)	9 cfs	39 cfs	27 cfs
Post Developed EB Allowed Peak Discharge (cfs)			
Storage Volume Reqd., (ac-ft)			

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Energy Balance Design Example

- Compute the Energy Balance (EB) Allowed Peak Discharge (with and without RR):

$$q_{1post} \leq q_{1pre} \left(\frac{RV_{pre1}}{RV_{post1}} \right) (IF)$$

<u>without RR</u>

$$q_{1post} \leq 9cfs \left(\frac{0.62"}{1.28"} \right) (0.8)$$

$$q_{1post} \leq \mathbf{3.5\ cfs}$$

<u>with RR</u>

$$q_{1post} \leq 9cfs \left(\frac{0.62"}{0.96"} \right) (0.8)$$

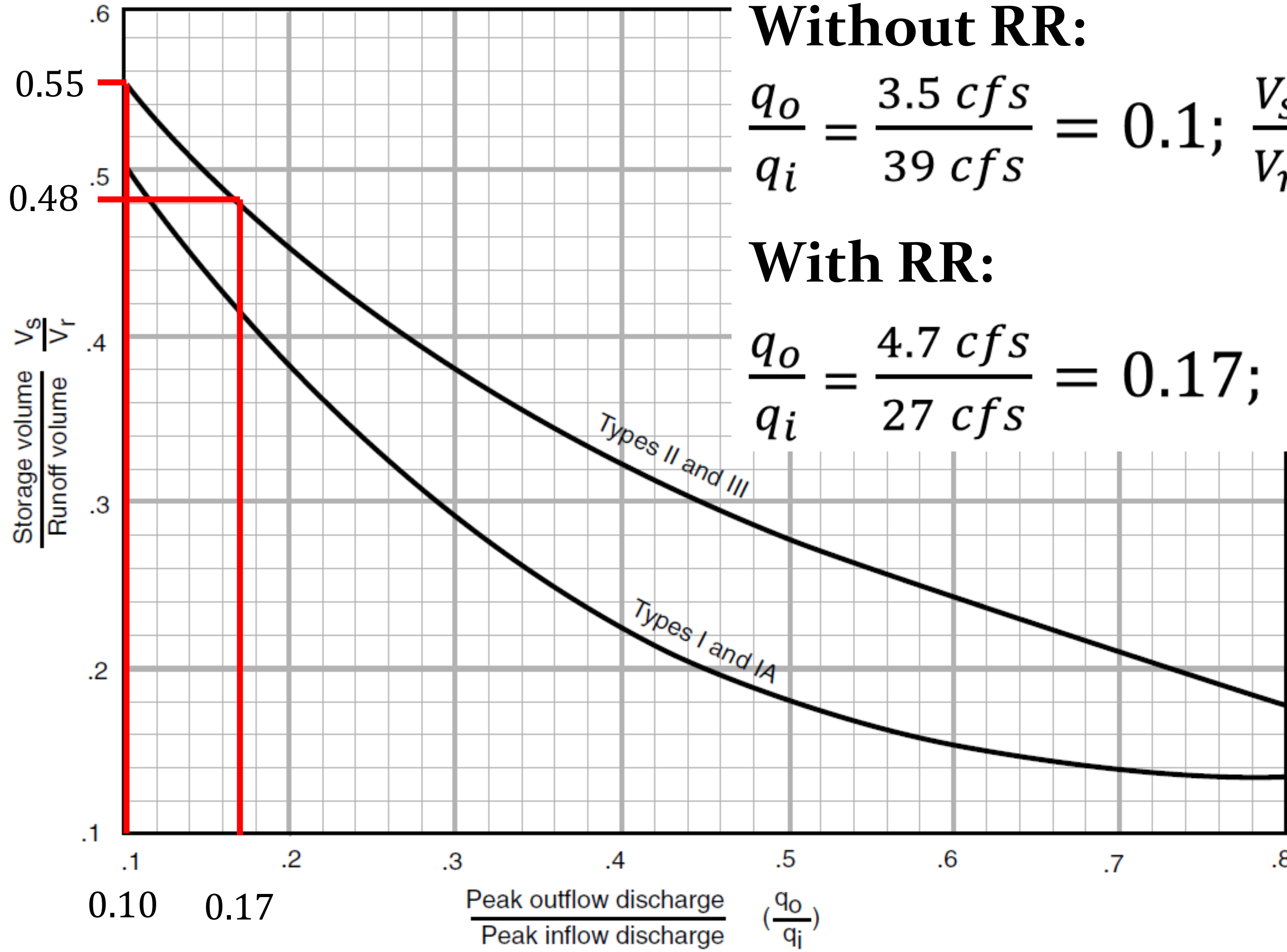
$$q_{1post} \leq \mathbf{4.7\ cfs}$$

Energy Balance Design Example

One-Year Storm Hydrology Summary: 19.8 acres			
	Pre-Developed	**Post-Developed no RR**	**Post-Developed with RR**
Runoff Curve Number	71	83	77
Runoff Volume (RV)	0.62 in	1.28 in	0.96 in
Runoff Volume	1.02 ac-ft.	2.11 ac-ft.	1.58 ac-ft.
Peak Discharge (q_1)	9 cfs	39 cfs	27 cfs
Post Developed EB Allowed Peak Discharge (cfs)		**3.5 cfs***	**4.7 cfs***
Storage Volume Reqd., (ac-ft)			

1. **Increase in allowable discharge!**
2. **Energy Balance discharge not required to be less than ratio reduction for Forested condition**

Figure 6-1 Approximate detention basin routing for rainfall types I, IA, II, and III



Without RR:

$$\frac{q_o}{q_i} = \frac{3.5\,cfs}{39\,cfs} = 0.1;\ \frac{V_s}{V_r} = 0.55$$

With RR:

$$\frac{q_o}{q_i} = \frac{4.7\,cfs}{27\,cfs} = 0.17;\ \frac{V_s}{V_r} = 0.48$$

Energy Balance Design Example

- Compute the Storage Volume Required (V_s) to achieve the allowable peak outflow:

without RR	with RR
$\frac{q_o}{q_i} = \frac{3.5\ cfs}{39\ cfs} = 0.1$	$\frac{q_o}{q_i} = \frac{4.7\ cfs}{27\ cfs} = 0.17$
$\frac{V_s}{V_r} = \frac{V_s}{2.11\ ac-ft.} = 0.55$	$\frac{V_s}{V_r} = \frac{V_s}{1.58\ ac-ft.} = 0.48$
Storage Required (V_s) **= 1.16 ac-ft**	Storage Required (V_s) **= 0.76 ac-ft**

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Energy Balance Design Example

One-Year Storm Hydrology Summary: 19.8 acres			
	Pre-Developed	**Post-Developed no RR**	**Post-Developed with RR**
Runoff Curve Number	71	83	77
Runoff Volume (RV)	0.62 in	1.28 in	0.96 in
Runoff Volume	1.02 ac-ft.	2.11 ac-ft.	1.58 ac-ft.
Peak Discharge (q_1)	9 cfs	39 cfs	27 cfs
Post Developed EB Allowed Peak Discharge (cfs)		**3.5 cfs**	**4.7 cfs**
Storage Volume Reqd. (ac-ft)		**1.16 ac-ft.***	**0.76 ac-ft.***

37% Reduction in required 1-yr Channel Protection Storage Volume

VRRM Compliance Spreadsheet Limitations

- Spreadsheet uses different Land Cover terminology than NRCS Methods
- Not single-event routing model
- Reflects *annual* volume & *annual* pollutant load reduction
- VRRM spreadsheet does not reflect over-sized practices
- CN Adjustment based on annual credit
  - Predicated on required practice sizing

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VRRM Compliance Spreadsheet Limitations

- Multiple treatment trains difficult to compute?
  - Aggregated practices (e.g., several lots of simple impervious disconnection)
    - Do **not** all flow to same type of downstream practice
    - Must be aggregated on separate DA tabs based on common downstream practice

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VRRM Compliance Spreadsheet Limitations

- Multiple treatment trains difficult to compute?
  - Spreadsheet **cannot** track aggregated volume from multiple treatment trains displayed on separate DA tabs into single downstream practice
  - Designer **must** track volume independently of spreadsheet

5d. Flood Protection

Virginia Department of Environmental Quality

Water Quantity Criteria Flood Protection

9VAC25-870-66. localized flooding:

Demonstrate:

***No 10-yr flooding now**

*** No 10-yr flooding after development**

*** and 1% Rule analysis**

Local flooding?

<u>Must</u> eliminate flooding by:

*** on-site detention**

*** system improvements**

*** combination**

*** and 1% Rule analysis**

OR:

*** Detention of 10-year peak flow to less than existing**

*** No further** (1% Rule) **analysis required**

5e. Limits of Analysis

Water Quantity Control Compliance

1% Rule Analysis:

- Downstream capacity analysis carried to a point where:
  - Site's contributing DA is < 1% of total watershed area **or**
  - Site's 10-yr contributing peak flow rate is < 1% of total watershed area
    (before implementation of any quantity detention)

Sheet Flow

9VAC25-870-66. Water quantity.

D. Increased volumes of sheet flow resulting from pervious or disconnected impervious areas, or from physical spreading of concentrated flow through level spreaders, must be identified and evaluated for potential impacts on down-gradient properties or resources.

Questions?